LIVE PROBING AND CONVENTIONAL TECHNIQUES FOR PREDICTING BEEF CARCASS COMPOSITION ADJUSTED FOR WEIGHT DIFFERENCES BY REGRESSION AND RATIO

By

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BY REGRESSION AND RATIO

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INTRODUCTION

The consumer's objection to excessive fat has been channeled through the retailer, packer and feeder to the breeder who must produce the kind of cattle that will be high yielding in terms of boneless cuts. Identification of the kind of cattle that will produce the desired retail cuts is more effective at the carcass level than in the live animal, yet the breeder needs to identify this type in the live animal for maximum progress in his breeding program.

The rate of genetic change per unit of time usually favors individual selection when the heritability of the trait is high (Dickerson and Hazel, 1944; Falconer, 1960). Assume the following:

(1) The heritability of a trait equals 0.50.

(2) The trait can be measured equally well in the live animal and in the carcass.

(3) The generation intervals are four and six years for individual and progeny test selection.

(4) The intensity of selection is one in five and one in 20 for progeny test and individual selection, respectively.

Under these conditions the rate of progress is approximately 2.4 times as fast for individual selection as compared to selection on the basis of a progeny test.

At the carcass level fat trim has been reported as the largest single factor affecting the percentage yield of boneless retail cuts from a side of beef (Hicks and Hazel, 1965). In fact, Hedrick et al. (1965) reported that subcutaneous fat thickness measurements (estimators of fat trim) were associated with two to three times as much of the variation in retail yield as were longissimus dorsi area measurements (estimators of muscle). Earlier, Murphey et al. (1960) reported that finish was four and one-half times as important as conformation in predicting yields of closely trimmed mostly bone-in retail cuts from the four major wholesale cuts. Regardless of the precise importance of fat relative to the other variables which influence retail cut yield, the fact remains that carcass fat trim has a large effect. Thus, several research attempts have been made to identify fat variation in the live animal.

Subjective appraisal is a method for evaluating fatness which has been widely used in beef cattle research. Wilson et al. (1964) and Gregory et al. (1964) found that experienced cattle appraisers are reasonably accurate when evaluating fatness in cattle. That this method is not wholly adequate is attested by a quote from Gregory et al. (1962) which states, "When working with cattle from a homogenous population, as would be the case in practice, it is apparent that graders cannot rank individual animals on the basis of either quantitative or qualitative carcass traits with the precision necessary to provide a basis for selecting among breeding cattle for differences in these traits."

Ultrasonic equipment has provided more information on carcass fatness in the live animal than has subjective appraisal. But the large costs involved in terms of initial purchase of the equipment, training of the operator and interpretation of the recordings have limited the widespread utilization of this technique.

A mechanical probe (ruler) was found to be an effective method for measuring carcass fatness in swine (Hazel and Kline, 1952). The low cost and ease of application combined with the high correlation that exists between probed backfat and trimmed lean cut yield have made the probing method one of real value to the swine breeder. As first suggested by Hazel and Kline (1952) and later confirmed by Hazel and Kline (1959) and Bowman et al. (1960), the live probed fat measurement in swine was more highly correlated with percentage lean cut yield than was the carcass backfat measurement.

The real value of predicting the percentage yield may be questioned when one considers the weight of the product as the desired trait. If this is the case a much simplier method may be employed for measuring the trait. Swiger et al. (1964) studied a group of calves born the same season, raised similarly and in many respects quite typical of a calf crop that would be subject to selection by the breeder. In this report Swiger et al. (1964) found that carcass weight alone accounted for 93 percent of the variation in total weight of retail product. They also found that the addition of a live measure (ultrasonic or subjective) of fatness improved only slightly the estimate of total retail product.

The work of Birkett et al. (1965) suggests another problem, namely, that of properly adjusting data from carcasses differing in weight. They obtained negative correlations of low magnitude to essentially zero for linear measurements and percentage yield of closely trimmed wholesale cuts when the effects of carcass weight were not removed.

They attempted to adjust for differences in carcass weight by using partial correlation analysis, holding carcass weight constant. This increased the magnitude of the correlations, but even these were not as high as when the carcass weight adjustment was made by dividing the linear measurement by carcass weight and multiplying the quotient by 100. This leads to the problem considered by Dinkel, et al. (1965) who implied that ratios and percentages are not proper adjustments for carcass weight differences for many of the carcass measurements currently employed.

This study was undertaken with the following objectives:

(1) to evaluate the thermister probing technique for predicting beef carcass fatness,

(2) to consider the relationships between several commonly used measurements and carcass composition and

(3) to examine the use of ratios and regressions for adjusting the data for differences in weight.

LITERATURE REVIEW

Estimating Carcass Fatness and/or Cutability

Live Animal Techniques

Subjective Appraisal. Perhaps the most widely employed method for evaluating condition (or fatness) of livestock is by means of subjective appraisal. This procedure is also used to estimate cutability of the carcass. Gregory et al. (1964) reported on some relationships between subjective estimates of carcass traits. Their study was comprised of 204 steers which were of the Angus, Hereford and Shorthorn breeds and the six reciprocal crosses. Three graders had correlations between estimates and actual measurements of carcass fat thickness of 0.36 to 0.52. The correlations involving rib eye areas ranged from 0.33 to 0.58. Subjective estimates of carcass cutability were found to account for 20 to 25 percent of the variation in carcass traits (Gregory et al., 1962), but as the graders gained more experience it was found that subjectively estimated cutability accounted for 25 to 35 percent of the variation in carcass cutability (Gregory et al., 1964).

Subjective and carcass measured fat thickness were significantly correlated (0.52) on a group of 51 Hereford and Hereford-Charolais steers according to Davis et al. (1965a). In the same cattle a correlation of 0.51 was found between estimates and carcass measured rib-eye areas. Somewhat lower correlations were reported between live estimates and carcass measures of these two variables by Wilson et al. (1963) who reported correlations of 0.38 and 0.33 for fat thickness and rib-eye area, respectively. The latter study was comprised of 135 grade Hereford steers. This group of researchers also reported a relationship between live- and carcass-estimated cutability of 0.44. Later, Wilson et al. (1964) reported a multiple correlation of 0.51 between actual cutability and predicted carcass cutability. The predicted cutability was based on actual live weight and live animal estimates of fat thickness, rib-eye area and percentage kidney fat. These researchers had a correlation of 0.65 between live-estimated fat thickness and carcass cutability, which suggests some value for subjectively estimated fat.

Backfat Probe in Swine. Hazel and Kline (1952) described a method for measuring backfat thickness in swine. They made a small opening in the hide and inserted a metal ruler through the soft fat to the firm tissue overlying the muscle. The probe sites were approximately one and one-half inches off the midline of the body at points immediately behind the shoulder, the middle of the back and near the middle of the loin. When these measurements were related to estimators of carcass muscle it was found that the live probes were more accurate indicators of carcass value than were the carcass backfat measurements. As an explanation, Hazel and Kline (1952) suggested that carcass backfat is measured from the tips of the vertical processes on the vertebral column; whereas, the live measurement records fat depth overlying the longissimus dorsi muscle. The findings of this study were further substantiated by at least two papers. Hazel and Kline (1959) found r^2 values between live backfat and percentage lean cuts and carcass backfat and percentage lean cuts of 0.79 and 0.72, respectively.

Lower relationships were reported by Bowman et al. (1962); however, they also showed an advantage to the live measurement of fatness, with the live and carcass measurements accounting for 48 and 36 percent of the variation in percentage carcass muscle, respectively.

Thermister Thermometer Probe. The use of a thermister thermometer for estimating fat thickness on live cattle was first reported by Warren et al. (1959). These researchers probed steers at a location dorsal to the *longissimus dorsi* directly over the 13th rib or over the transverse process of the second lumbar vertebra. They made three probes three to four cm. apart midway between the loin midline and the edge of the loin. The probing device was sensitive to the temperature differential between fat and muscle tissues, so as this change was detected on the temperature dial the depth of the needle insertion was recorded and considered to be a measure of fat which included hide thickness. The simple correlation coefficient between fat probe and carcass fat thickness over the loin on 12 long-fed, highly finished, heavy steers was 0.75. Another group of 49 steers were measured in the same manner and a correlation of 0.47 was obtained between the two measures of fat thickness (live and carcass). At the Second Coordinated Beef Improvement Conference on live animal and carcass evaluation Warren (1963) reported that a correlation of 0.62 was obtained between live probed estimates and actual carcass measured fat thickness.

Ultrasonics. One of the first reports on the use of ultrasonics for estimating fat thickness in live cattle was given at the seventh western sectional meeting of the American Society of Animal Production in 1956 by Temple et al. (Hedrick et al., 1962). Hedrick et al. (1962)

suggested that Temple et al. had results indicating that ultrasonic equipment was reliable for estimating fat thickness. Stouffer et al. (1961) and Hedrick et al. (1962) reported correlations between ultrasonic and carcass measures of fatness of 0.04 to 0.54 and 0.11 to 0.63, respectively, which were somewhat lower than those found in swine up to that time. One reason given for the rather low correlations as reported by Hedrick et al. (1962) was that the scribing process practiced by the packer allowed the fat and muscles to rotate away from the spinous processes of the thoracic vertebrae and thus alter the fat thickness in the carcass. Another frequently mentioned problem was the inability of the operator to interpret the recordings made by the earlier models. The rather low correlations combined with the high equipment cost limited the use of ultrasonics in beef cattle. But more recently the technique difficulties have been overcome, with lighter, more economical units. Reports by Brown et al. (1964), Davis et al. (1964a, 1965a), Meyer et al. (1965) and Temple et al. (1965) have shown correlations of 0.90 and above between live and carcass measured fat thickness. These researchers made no mention of the amount of variation in fat thickness for the groups studied. The amount of variation has an influence on the magnitude of the correlations obtained. Sumption et al. (1964) reported a pooled correlation of 0.63 between carcass and ultrasonically measured fat on 770 bulls, steers and heifers. Since these correlations were computed on a within group, sex and treatment basis, the groups would perhaps be similar to those which a breeder might encounter in selection within a herd. Correlations computed on a within sex basis ranged from 0.57 to 0.75 for the live and carcass measured fat thickness according to Davis et al. (1965b).

The thermister probe and ultrasonically estimated live fat thickness measurements were all taken in the vicinity of the 12-13th rib, except for a few probes made by Warren et al. (1959) over the lateral process of the second lumbar vertebra. A reason for choosing the 12-13th rib site is that fat thickness in the carcass is often measured at this location, and it has been reported to have a high degree of association with carcass fat trim. It should be recognized that the live measurement of fat in this region is only an estimator of the carcass fat over the longissimus dorsi muscle, which in turn is only an estimator of carcass fatness.

Carcass Techniques

Hicks and Hazel (1965) reported that fat trim accounted for 81 percent of the variation in beef carcass value after the effects of weight differences were removed by linear regression. Their study was comprised of 257 Angus and Hereford steer carcasses. Carcass value was based on average market value for the various cuts from the entire carcass. The 12-13th rib site has been reported to be the single most valuable easily obtainable carcass measure for estimating fat trim by Ramsey et al. (1962) and further substantiated by Murphey et al. (1963). Ramsey et al. (1962) made their observations on 133 steer carcasses coming from eight breeds (Angus, Hereford, Brahman, Brahman-British crosses, Santa Gertrudis, Jersey and Holstein). The steers' weight range was restricted by slaughtering at 900 pounds or 20 months, which ever was reached first. However, even with the weight restriction, slaughter weight ranged from 525 to 887 pounds. The simple correlation coefficient between a single fat thickness measurement over the longissimus dorsi at the 12th rib and percentage separable carcass fat was 0.82. Results similar to these were found by Brackelsberg (1963) in a physical separation study which involved 20 steers of the Angus, Hereford and Shorthorn breeds. When breed was ignored the simple correlation between average 12th rib fat thickness and total carcass separable fat was 0.82. This group of cattle was very uniform with the range in side weights being 226 to 255 pounds. The correlation of 0.82 reported by Ramsey et al. (1962) was lowered to 0.68 when computed on a within breed basis, which would have greater application to the types of cattle involved in most selection studies on a single breed herd. Gottsch et al. (1961) found a somewhat smaller correlation (0.57) between the same two variables when working with 38 Hereford steers. Fitzhugh et al. (1965), who studied 152 Hereford steers, found a partial correlation of 0.75 between fat thickness and weight of the total carcass fat when weight of the carcass was held constant.

Yield grade (estimated cutability), a trait highly influenced by carcass fat, was found to have high relationship to average fat thickness by Ramsey et al. (1962), with the magnitude of correlation being 0.80 and 0.65 when calculated across and within breeds, respectively.

A study conducted by Murphey et al. (1963) involved 277 beef carcasses which were selected to represent all yield and quality grades. The correlation between single fat thickness measurement and yield of closely trimmed, boneless retail cuts was -.72. An even smaller correlation (-.54) was obtained by Zinn et al. (1961) who dealt with 48 Hereford and 48 Angus steer carcasses averaging U.S. Good quality grade. Brungardt and Bray (1963) selected the left sides from 33 steer carcasses of U.S. Choice grade within each of three weight groups:

(1) 260-288 pounds, (2) 300-325 pounds and (3) 332-360 pounds. Their correlation between 12th rib fat thickness and percentage retail yield was -.71, which is somewhat higher than the -.61 found by Stringer et al. (1963). The latter group worked with 194 carcasses grading U.S. Good, Choice and Prime. Carcasses from 96 purebred and crossbred steers sired by Angus, Brahman, Brangus, Charolais, Hereford and Shorthorn bulls were examined by Koonce et al. (1963). In these data a correlation of -.62 was found between fat thickness and yield grade.

Some evidence indicates that a reliable live measure of fat may be as good or even better than the carcass measure as an indicator of fat trim. The results of Hazel and Kline (1952, 1959) and Bowman et al. (1962) indicated that live measurements of backfat thickness in swine were more accurate indicators of carcass value than were the carcass backfat measurements. In addition, some factors have been identified as causes for error in the fat thickness measurement on beef carcasses. Temple et al. (1965) noted that fat removed with the hide produced differences in actual and carcass measured fat of up to 0.5 cm. The fat removed with the hide is likely to have a larger effect in some specific regions of the carcass than on the total carcass fat. Ramsey et al. (1965) also mentioned that changes in fat configuration could have an effect on the correlation between live and carcass fat. The scribing process practiced by many packers tends to allow the fat and muscles to rotate away from the spinous processes of the thoracic vertebrae, thus modifying the carcass measure of fat thickness. Sumption et al. (1964) reported that the live measure of fat five cm. from the midline had a lower correlation with the corresponding carcass measurement than did the measurements taken nine and thirteen cm. from the midline. The measurement nearest the midline presumably would be affected most by the scribing process. One other factor that would tend to lower the correlation between the live and carcass measure is the shifting of fat and muscle from its natural position when hung on the rail. Temple et al. (1965) reported that some live measurement sites shifted as much as five cm. in relation to the skeleton when the carcass was hung.

At this time one can only postulate as to the true relationship that exists between a live measure of fatness and actual carcass fat trim; but it seems possible that a live measurement could be just as reliable as a carcass measurement when considering the changes in the carcass fat thickness brought about during the process of slaughter. Perhaps Lush (1928) surmised the situation when he stated, "In the geometrical sense the animal body is of such a complicated shape that any one or few measurements could approximate a description of it in only the crudest way."

Statistical Adjustment for Carcass Weight Differences:

Ratio vs. Regression

Two methods for adjusting carcass data from animals differing in weight are: linear regression of the form $Y = a + b\ (x - \bar{\bar{x}})$ and percentage where a carcass measurement is divided by carcass weight. Dinkel et al. (1965) suggested that ratios and percentages, when used as measures of carcass traits, should receive careful scrutiny by the one who used them. Snedecor (1946) recognized that ratios are used extensively, and in some cases their appropriateness may be questioned.

For example, the ratio Y/X (feed required per pound gain) can be used to predict gains in pigs. Some data used by Snedecor (1946) to exemplify this situation produced a regression which underestimated the gains of pigs which ate heavily, and overestimated the others. This is due to the fact that the regression line through the origin does not depict the behavior of the animals.

A linear regression was used to correct longissimus dorsi area in lambs by Esplin et al. (1964). In this case it was found that the regression gave a normal distribution and it removed several times more variance in loin eye area than did the direct ratio method. The ratio (loin eye area/carcass weight) overcorrected loin eye areas from light and undercorrected them from heavy carcasses.

Swiger (1962) discussed the use and misuse of percentages at the 14th annual NC-1 meeting. He indicated that many measures of carcass traits have true regressions which pass through the origin, but these are seldom linear. Swiger (1962) further suggested that linear regression may suffice for the range in carcass weights encountered in a specific study but this does not mean that a ratio or percentage would be appropriate. This is due to the fact that the true regression may be curvilinear from zero weight to the range of weights encountered in the study. Thus, a linear regression fitted to the data would not pass through the origin whereas a ratio would force the slope through this point thereby increasing the sum of squared deviations from each observation to the line.

Apparently there are two conditions which should be met before a ratio is a proper data adjustment procedure. They are as follows:

(1) the true regression should pass through the origin and

(2) the slope of the line must be linear through the region of interest.

MATERIALS AND METHODS

Phase One

Source of Data

All livestock used in this study were a part of project 1256 which is Oklahoma Agricultural Experiment Station's contribution to NC-1, "Improvement of Beef Cattle Through Breeding Methods." The Angus bulls, steers and heifers and Hereford steers were slaughtered at approximately 383 days of age following a 154-day feeding trial. The calves were weaned at an average age of 205 days prior to the start of the feeding period. Table I contains a listing of the cattle involved in this study by year, breed and sex group.

TABLE I

CATTLE INVOLVED IN THIS STUDY

Year	Breed	Sex[a]	No.
1964	Angus	B	9
	Hereford	S	77
	Angus	H	27
	Angus	S	61
1965	A, H and S[b]	S	12
	Hereford[c]	S	79
	Angus[c]	H	44
	Angus[c]	S	31
	Angus[c]	B	40

[a]B = bull; S = steer; H = heifer.
[b]3 Angus; 8 Hereford; 1 Shorthorn.
[c]Groups from which 51 cattle were chosen for the second phase of this study.

Live Techniques

In the first phase of this study an attempt was made to refine a probing technique for measuring fat thickness in the live animal. Three sites were selected for probing. They were in the general vicinity of those used when measuring average carcass fat thickness over the longissimus dorsi at the 12th rib as outlined by Naumann (1951). The probe sites were located over the space between the 12th and 13th ribs at positions five (R5), nine (R9) and thirteen (R13) cm. lateral to the midline of the back. A hide puncture was made with an ordinary bleeding needle which was equipped with a rubber handle. The depth of the needle puncture was restricted so that it merely made an opening through the hide. Unless caution was exercised, the underlying muscle was also penetrated on cattle having minimal backfat thickness. The hide puncture made an opening large enough so that the 16 gauge thermister needle[1] could enter and exit freely. When the needle was inserted to sufficient depth for muscle contact, the operator indicated the depth of insertion by placing his digital nail against the probe immediately adjacent to the animal's hide. Upon withdrawl of the probe the depth of insertion was recorded to the nearest one-fourth millimeter (approximately 0.01 inches). Muscle contact was determined by observing the temperature increase on the recording dial. As the operator gained experience, he became less dependent on the temperature gradient from fat to muscle for evidence that muscle was being approached,

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[1] The thermister probing needle and temperature dial were obtained from the Cole-Parmer Instrument Company. The needle has thermister beads located near its tip which detect and relay temperature to the dial.

but rather relied on his sense of touch to indicate muscle contact. Muscle contact was evident when the sharp needle tip began to catch in the connective tissue-perimysium. Occasionally there was some animal reaction when this contact was made.

Animal restraint consisted of placing the subject in a squeeze chute. Fat thickness measurements were made only when the animal stood in an upright position. Site preparation consisted of clipping the hair coat and swabbing the area with a 70 percent alcohol solution prior to making the hide puncture.

Carcass Techniques

The following carcass data were obtained from the cattle involved in the first phase. Hot carcass weight was recorded at the time of slaughter. Trimmed round was cut as outlined by Brungardt and Bray (1963). The longissimus dorsi area and fat thicknesses were measured from acetate tracings made in the cooler after the carcasses were quartered in the normal manner between the 12th and 13th ribs. Average fat thickness (as described by Naumann, 1951) and single fat thickness were measured. The single fat measure was taken at a representative point approximately three-fourths the distance from the medial end of the longissimus dorsi cross section. Percentage kidney and pelvic fat were estimated subjectively. Carcass cutability was computed by the following two equations developed and reported by Murphey et al. (1960).

Percentage boneless retail cuts from round, loin, rib and chuck = 52.56 - 4.95 (single fat thickness over rib-eye, inches) - 1.06 (percentage kidney fat) + 0.682 (area of rib-eye, square inches) - 0.008 (carcass weight, pounds).

Percentage boneless retail cuts from round, loin, rib and chuck = 52.66 - 5.33 (average fat thickness over rib-eye, inches) - 0.979 (percentage kidney fat) + 0.665 (area of rib-eye, square inches) - 0.0065 (carcass weight, pounds).

Carcass cutability was also calculated using the equation developed by Brungardt and Bray (1963) wherein:

Retail yield = 16.64 + 1.67 (percentage trimmed round) - 4.94 (single fat measurement at the 12th rib, inches).

The carcass conformation and marbling scores, maturity group, final grade and estimated kidney fat were all taken by well-trained and qualified personnel from the beef division of Maurer-Neurer Packing Company at Arkansas City, Kansas. The conformation and final grades were recorded to the nearest one-third grade according to the U.S.D.A. standards for Prime, Choice, Good, Standard and Utility.

Phase Two

Source of Data

The 51 cattle in this phase were comprised of 20 Hereford steers and 13, 10 and 8 Angus bulls, steers and heifers, respectively. The cattle came from the groups indicated in Table I. Two Hereford steers were randomly chosen from each of ten sires, and at least one bull, steer and heifer were sired by each of eight Angus bulls.

Live Techniques

Four other sites were chosen for probing in addition to the three already mentioned in phase one. They were at locations eight cm. lateral to the thoracic vertebrae, dorsally to the posterior edge of the scapula (T8); eight cm. lateral to the sacral vertebra, dorsally to the posterior edge of the tuber coxae ($S_1 8$); eight cm. lateral to the last site ($S_1 16$); and another eight cm. posterior to the $S_1 8$ site ($S_2 8$).

Carcass Techniques

The right sides of these carcasses were returned to the Oklahoma State University meat laboratory where specific gravity determinations of the fore and hind-quarter were made. The sides were subsequently cut into thick and thin muscles, fat trim and bone as described by Martin (1965) and Martin et al. (1966) with the following modifications: the major muscles and muscle systems were not trimmed of portions less than 5.1 cm. and 7.6 cm. in thickness for muscles and muscle systems coming from the hind and fore-quarter, respectively. In this study all of the carcass fat, bone and muscle was considered as total carcass weight. Correlations and predictions were based on total carcass fat, muscle and bone rather than streamlined carcass components as reported by Martin (1965). This carcass cutting procedure was chosen because it would give an objective measurement of carcass fat trim. All cuts were trimmed of fat in excess of 5 to 7 mm. and the resulting muscle and fat trim were entirely boneless, therefore a measure of carcass bone could also be obtained. The close trimming of fat from all muscles and muscle systems made it possible to standardize the amount of fat remaining with the saleable product from carcass to carcass much more uniformly than would have been the case using conventional cutting techniques.

Statistical Procedures

The major portion of the data was analyzed using simple correlation and regression techniques as outlined by Steel and Torrie (1960). In addition, least squares (multiple regression) analysis was used for the data obtained from the 51 cattle used in the second phase of this investigation. The model assumed for the least squares analysis was as follows:

$$\hat{Y}_{ij} = \bar{Y}_i + \sum_{j=1}^{4} \beta_j x_j + \sum_{j=1}^{4} \beta_j x_j^2 + e_{ij}$$

where:

$\hat{Y}_{ij}$ = adjusted carcass fat, muscle or bone for the jth calf in the ith breed and sex group,

$\bar{Y}_i$ = mean for fat, muscle or bone for the ith breed and sex group,

x_j = deviation of the jth observation from the ith group mean,

β_j = jth constant associated with the jth measurement and

e_{ij} = random effect peculiar to each animal.

The normal equations for this model using matrix notation were:

$$[X'X]\ [\beta] = [X'Y]$$

where the $[X'X]$ was comprised of the corrected sums of squares and cross products pooled within breed and sex of calf, assuming equal variances among observations within separate classes. The $X'X$, $X'Y$ arrays appeared as follows:

$$
\begin{array}{cc}
[X'X] & [X'Y] \\
\begin{bmatrix}
X_{11} & X_{12} & \cdots & X_{1n} \\
X_{21} & X_{22} & \cdots & X_{2n} \\
\vdots & & & \vdots \\
X_{m1} & \cdots & \cdots & X_{mn}
\end{bmatrix}
&
\begin{bmatrix}
X_1Y \\
X_2Y \\
\vdots \\
X_mY
\end{bmatrix}
\end{array}
$$

where:

X_{11} = sums of squares for variable one corrected for mean differences and pooled from the four groups,

X_{12} = sum of cross products for variable one and variable two corrected and pooled as above,

.

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.

X_{mn} = etc.,

X_1Y = sum of cross products for variable one with Y,

X_{ii} = independent variables and

Y = dependent variable.

The vector of betas may be represented as follows:

$$
[\beta] = \begin{bmatrix}
\beta_1 \\
\beta_2 \\
\vdots \\
\beta_n
\end{bmatrix}
$$

where:

β_1 = the beta corresponding to variable X_1,

β_2 = the beta corresponding to variable X_2,

.
.
.

β_n = the beta corresponding to variable X_n.

The least squares constants were estimated by inverting the $[X'X]$ accompanied by the $[X'Y]$ on the right hand side with the O.S.U. Computer Center library program.[2] This routine resulted in the $[X'X]^{-1}$ accompanied by the vector of betas on the right hand side.

The total reduction due to fitting all constants was computed by multiplying the vector of constants, $[\beta]$, times the right hand side vector, $[X'Y]$. The reduction in sums of squares for each specific variable after the effects of all others were held constant was obtained by multiplying the constant times the inverse of the segment of the $[X'X]^{-1}$ corresponding by row and by column to the constant; this product was again multiplied by the constant.

The total reduction sums of squares was computed for the model which contained the linear and quadratic terms for each of four variables. The variables were sequentially eliminated when it was found that they did not contribute significantly to the total reduction in sums of squares.

Multiple correlation coefficients were computed by the Doolittle procedure using the simple correlation matrices. The most useful

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[2]This routine was adapted for the IBM 7040 by Edgar Butler, Graduate Assistant, Mathematics and Statistics Department, Oklahoma State University.

equations were selected and multiple regressions were calculated by the procedure proposed by Doolittle as set forth by Steel and Torrie (1960).

RESULTS AND DISCUSSION

The Relationship Between Live and Carcass Fat Thickness Measurements

Fat thickness over the longissimus dorsi at the 12th rib was measured alive and in the carcass on 380 bulls, steers and heifers. The means and standard deviations of the average carcass fat thickness are presented in Table II for each sex group on a within lot basis. All lots except the group of 12 show steers were a rather homogeneous grouping within breed, sex and management regime and would be quite similar to the types of cattle which are apt to be encountered in selection for carcass traits. The simple correlation coefficients between the live and carcass measures of fat over the longissimus dorsi at the 12th rib are presented in the last column of Table II. The high correlation (0.90) on the group of show steers is presented to show the association between live and carcass measures of fat thickness which were obtained on cattle having considerable variation in carcass fatness (standard deviation = 0.64 cm.). In general, the correlations ranged from 0.50 to 0.80, but did go as low as 0.21 which was non-significant at $P < .05$. Lower correlations were associated with the groups having less variability as determined by the standard deviation of carcass fat thickness. These correlations ranged in value from 0.47 to 0.84 and compared favorably with those given by Warren et al. (1959) and Warren (1960, 1963). These reports made no mention of the amount of variation in the cattle probed.

TABLE II

MEANS, STANDARD DEVIATIONS AND SIMPLE CORRELATION COEFFICIENTS BETWEEN LIVE AND CARCASS MEASURED FAT OVER THE *LONGISSIMUS DORSI* AT THE 12TH RIB

Year	Breed	Sex[a]	No.	Carcass Fat (cm.) Mean	Standard Deviation	"r"
1964	Angus	B	9	0.99	0.41	0.82**
	Hereford	S	77	1.60	.41	.68**
	Angus	H	27	1.90	.41	.21
	Angus	S	61	1.88	.36	.44**
1965	A, H and S[b]	S	12	2.31	.64	.90**
	Hereford	S	79	1.70	.38	.73**
	Angus	H	44	1.70	.33	.53**
	Angus	S	31	1.78	.30	.58**
	Angus	B	40	1.37	.28	.37*

[a]B = bull; S = steer; H = heifer.
[b]3 Angus, 8 Hereford and 1 Shorthorn (4H and FFA show steers).
*Level of significance = $P < .05$.
**Level of significance = $P < .01$.

Ultrasonic equipment has been used to measure fat thickness in beef cattle. Correlations between the live and carcass measurements of fat thickness have ranged from 0.04 to 0.96 with the major portion of the estimates within the range of 0.50 to 0.80 (Stouffer et al., 1961; Hedrick et al., 1962; Brown et al., 1964; Sumption et al., 1964; Temple et al., 1965; Davis et al., 1964a, 1965a; Davis et al., 1964b, 1965b; Meyer et al., 1965; Ramsey et al., 1965). The higher correlations have appeared most recently, suggesting that operator technique and mechanical function have improved. The literature indicates that ultrasonic methods are perhaps more precise than are the probing techniques for measuring fatness, although no direct comparisons between the two methods, on beef cattle, have been published.

A comparison between ultrasonically measured fatness and probed backfat in swine was given by Hazel and Kline (1959). Their results indicated no advantage for either method relative to predicting percentage lean cut yield.

The Angus steers and heifers probed in 1964 yielded somewhat lower correlations than the remaining groups. A different operator probed these groups, recording the live measurement to the nearest 1.25 mm.; whereas, recordings were made to the nearest 0.25 mm. (approximately) by another operator on all other groups.

Possible factors reducing the magnitude of correlation between live and carcass measures of fatness, in addition to inherent errors in the technique and ability of the operator were (1) scribing of the chine bones which changes the fat configuration by allowing the muscles and overlying fat to rotate away from the spinus processes of the thoracic vertebrae (substantiated by Ramsey et al., 1965); (2) the removal of fat with the hide in the vicinity of the measurement site, a source of error suggested by Temple et al. (1965) and substantiated in this study by observation of the carcasses following slaughter; (3) shifting of the muscles and fat from their normal position in the live animal relative to the skeleton, when hanging on the rail (Temple et al., 1965, suggested that the live measurement site may shift as much as five cm. when hung on the rail) and (4) the tightness of the shroud at the precise position of the carcass fat thickness measurement. Since all of the listed factors tend to reduce the relationship between the live and carcass measurement of fat thickness perhaps the live measurement would be as highly associated with total carcass fat trim as is the carcass measure of fat thickness at the 12th rib. This is based on the assumption that a small change in fat configuration at the 12th rib in the carcass has a larger effect on the average fat thickness measurement than on total carcass fat trim. This led to the second phase of the investigation which was to study the relationship of the live probed fat measurement and total carcass fat trim. In addition, predictors of total carcass muscle and bone were examined.

The Relationship Between Certain Measurements and Actual Carcass Composition

Population Description

Means and standard deviations are given in Table III for several of the measurements employed in the second phase of this investigation. The standard deviation of the single measurement of carcass fat thickness was 0.30 cm. which is considerably smaller than the value of 0.44

TABLE III

MEANS AND STANDARD DEVIATIONS FOR CERTAIN MEASUREMENTS

Measurement	Units	Mean	Standard Deviation
Live			
Slaughter weight	kilograms	385.	38.2
Slaughter age	days	383.	23.2
Weight per day of age	kilograms	1.01	0.086
Muscling score - grader A	see Appendix	10.5	0.99
grader B	see Appendix	10.6	1.00
Condition score[a] grader A	1/3 grade	10.2	1.08
grader B	1/3 grade	11.1	0.90
grader C	1/3 grade	10.7	1.04
Conformation score[b] grader A	1/3 grade	10.1	1.01
grader B	1/3 grade	10.8	0.83
grader C	1/3 grade	10.5	1.07
Fat probe R5[c]	cm.	1.66	0.289
R9	cm.	1.67	0.301
R13	cm.	1.78	0.318
T8	cm.	2.30	0.597
$S_1 8$	cm.	1.95	0.370
$S_1 16$	cm.	2.01	0.425
$S_2 8$	cm.	2.01	0.437
Carcass			
Hot carcass weight	kilograms	241.	26.6
Specific gravity		1.0458	0.00601
Trimmed round weight (left)	kilograms	25.4	2.77
Trimmed round (left)	percentage	21.4	1.00
Carcass conformation[b]	1/3 grade	11.0	1.11
Marbling score[d]		4.9	1.21
Final grade[b]	1/3 grade	9.9	1.23
Area of *longissimus dorsi*	square cm.	70.2	7.19
Fat thickness (average)	cm.	1.59	0.343
Fat thickness (single)	cm.	1.26	0.303

TABLE III (Cont.)

Measurement	Units	Mean	Standard Deviation
Carcass (Cont.)			
Estimated kidney fat	percentage	3.4	0.51
Fat unadjusted	kilograms	37.5	6.47
Muscle unadjusted	kilograms	63.5	6.81
Bone unadjusted	kilograms	14.2	1.48
Fat	percentage	32.5	3.29
Muscle	percentage	55.2	2.89
Bone	percentage	12.3	0.71
Fat adjusted for carcass weight	kilograms	37.5	3.76
Muscle adjusted for carcass weight	kilograms	63.5	3.25
Bone adjusted for carcass weight	kilograms	14.2	0.77
Fat adjusted for carcass and muscle weight	kilograms	37.5	1.42
Muscle adjusted for carcass and fat weight	kilograms	63.5	1.23
Bone adjusted for carcass and fat weight	kilograms	14.2	0.65
Carcass cutability - MA[e]	percentage	49.8	1.41
MS[f]	percentage	49.7	1.34
BB[g]	percentage	50.0	1.94

[a]Subjective prediction of carcass grade with 1 to 15 possible. Each full grade (Prime, Choice, Good, Standard, Utility) was divided into one-thirds with the values for high, average and low choice being 12, 11 and 10, respectively.

[b]Subjective evaluation of live animal shape using numerical scores which were the same as those for conformation score.

[c]Codes defined in Materials and Methods p. 16, 19.

[d]U.S.D.A. marbling score equivalents used as follows: 12 = extremely abundant, . . . 5 = small . . . and 1 = devoid.

[e]Murphey *et al.* (1960) equation using average fat thickness.

[f]Murphey *et al.* (1960) equation using single fat thickness.

[g]Brungardt and Bray (1963) cutability equation.

reported by Swiger et al. (1966). Three standard deviations of 0.48, 0.38 and 0.58 were reported by Gregory et al. (1962) for the single fat measurement. Gregory found standard deviations of the average fat thickness of 0.48, 0.41 and 0.66 which are also much larger than the standard deviation of 0.34 found on the 51 cattle in this study. This point is stressed to further emphasize the small amount of variation which existed for this trait. The results in Table II suggested that a higher relationship was found between the live and carcass fat thickness measurements when more variation was exhibited in this trait. Presumably the relationship between the live and carcass fat thickness measurements and the amount of actual carcass fat trim would be affected in a similar manner.

Carcass cutability estimated by the two Murphey et al. (1960) equations had standard deviations of 1.34 and 1.41 percent which is considerably less than the value of 2.06 percent found by Swiger et al. (1966). The cutability equation reported by Brungardt and Bray (1963) was developed from data which had standard deviations of 3.0 and 3.8 percent as compared to a standard deviation of 1.94 percent in these data. These results indicated that the 51 cattle were quite uniform with respect to estimated cutability.

These cattle were slaughtered on a time constant basis (all cattle within a group were fed the same length of time), so carcass weight varied considerably with a standard deviation of 26.6 kilograms. This variation is somewhat larger than the deviation of 23.0 kilograms found by Swiger et al. (1966). Since a measure of composition rather than growth rate was desired, a method for comparing carcasses differing in weight was needed (Swiger, 1962). The common practice of expressing the weight of the tissue as a percentage of total carcass weight could be used, but Swiger (1962) and Dinkel *et al.* (1965) have suggested that one exercise caution when using ratios.

Adjustment of Data for Differences in Weight

The simple correlation coefficient was used to evaluate the ratio and the regression procedures for adjusting data from carcasses differing in weight. The resulting correlations are shown in Table IV.

TABLE IV

SIMPLE CORRELATIONS BETWEEN CARCASS COMPONENTS WHEN ADJUSTED FOR DIFFERENCES IN CARCASS WEIGHT BY REGRESSIONS AND RATIOS

Variable	"r"
Fat adjusted by regression and percentage fat	0.92**
Muscle adjusted by regression and percentage muscle	.92**
Bone adjusted by regression and percentage bone	.89**

** Level of significance = $P < .01$.

On the basis of the relationships found, it was concluded that the two methods of adjustment were providing similar answers. Since the correlations were slightly less than perfect some discrepancy between the two was expected, but this discrepancy may not be large enough to cause serious errors in data similar to these. There are two possible causes for the correlations being less than unity. The data may not have a perfectly linear slope through the region of interest, or curvilinearity may exist between zero weight and the range of weights encountered in these data. The work of Swiger (1962), Esplin *et al.*

(1964), Dinkel et al. (1965) and Swiger et al. (1966) tend to support the latter cause.

An inquiry into the most precise method for adjusting carcasses differing in weight and composition was made. At the outset a model was constructed which contained terms for all variables thought to have a major effect on a certain tissue content of the carcasses. The general model for predicting fat was as follows:

$$\hat{Y}_{ij} = \bar{Y}_i + \beta_1 (A_j - \bar{A}_i) + \beta_2 (A_j - \bar{A}_i)^2 + \beta_3 (C_j - \bar{C}_i) + \beta_4 (C_j - \bar{C}_i)^2 + \beta_5 (M_j - \bar{M}_i) + \beta_6 (M_j - \bar{M}_i)^2 + \beta_7 (B_j - \bar{B}_i) + \beta_8 (B_j - \bar{B}_i)^2 + e_{ij}$$

where:

$\hat{Y}_{ij}$ = adjusted carcass fat for the jth calf in the ith sex group,

$\bar{Y}_i$ = mean fat content for the ith breed and sex group,

β = constant associated with the particular measurement,

$(A_j - \bar{A}_i)$ = deviation of the jth observation's age from the mean age of the ith group,

$(A_j - \bar{A}_i)^2$ = squared deviation of the jth observation's age from the average of the ith group,

.
.
.

etc.,

where C refers to chilled carcass weight; M refers to total carcass muscle and B refers to total carcass bone and

e_{ij} = random effect peculiar to each observation.

The total reduction sums of squares and squared multiple correlation coefficient were used to evaluate the goodness of fit of the model. Variables were deleted from the model in a sequential manner, when it was concluded that they made a small contribution to the total reduction in sums of squares. The results are given in Table V.

The model comprised of all variables accounted for a large portion of the variation in carcass fat trim (R^2 = 0.96). When the linear and quadratic terms were deleted for age, there was a surprisingly small decrease in the total reduction sums of squares. Apparently the range of age encompassing these data (standard deviation = 23 days) does not have a very significant effect on total carcass fat trim after the other variables have accounted for their portions of the total reduction sums of squares. Likewise, the R^2 was not markedly reduced after the linear and quadratic terms for bone were deleted from the model. However, the deletion of muscle or carcass weight produced a noticeable reduction in the TRSS and R^2. Therefore, the linear and quadratic terms for carcass weight and muscle were used in an equation which netted an R^2 of 0.95. Upon further deletion of terms it was found that the equation containing only linear components for carcass weight and muscle accounted for over 95 percent of the variation in fat trim; whereas, the models containing only carcass weight or muscle accounted for 66 and 21 percent of the variation, respectively. These results indicate that the linear adjustment of fat trim for differences in carcass weight or muscle individually leaves considerable variation unaccounted for; whereas, the model comprised of carcass weight and muscle in combination leaves much less variation in the error term. The model containing both carcass and muscle weights was used in this study to see whether a few or several easily obtainable measurements could be used

TABLE V

TOTAL REDUCTION SUMS OF SQUARES (TRRS) AND SQUARED MULTIPLE CORRELATION COEFFICIENTS (R^2) FOR SEVERAL MODELS TO PREDICT CARCASS FAT TRIM

Model[a]	TRSS	R^2
A, A^2, C, C^2, M, M^2, B, B^2	90,026,068	0.96
A, A^2, C, C^2, M, M^2, -, -	89,332,363	.96
A, A^2, C, C^2, -, -, B, B^2	72,817,298	.78
A, A^2, -, -, M, M^2, B, B^2	32,602,251	.35
-, -, C, C^2, M, M^2, B, B^2	90,008,798	.96
C, C^2, M, M^2	89,319,951	.95
C, C^2, -, -	61,808,469	.66
-, -, M, M^2	20,405,480	.22
C, -, M, -	89,021,044	.95
C	61,748,748	.66
M	19,540,628	.21

[a] $A = (A_j - \bar{A}_i)$ from overall model; $A^2 = (A_j - \bar{A}_i)^2$; . . . etc.

to predict total fat trim of the carcass after adjusting for differences in carcass weight and total muscle.

At this point fat trim was adjusted for carcass weight using a ratio, yielding percentage fat; it was adjusted by simple regression for differences in carcass weight; and was also adjusted by regression for differences in carcass and muscle weight. An attempt will be made to predict these three measures of fat trim in addition to total weight of carcass fat trim, unadjusted, in a later section.

The same procedure (as used for fat trim) was followed to arrive at an equation by which total carcass muscle could be adjusted. The model was as follows:

$$\hat{Y}_{ij} = \bar{\bar{Y}}_i + \beta_1 (A_j - \bar{\bar{A}}_i) + \beta_2 (A_j - \bar{\bar{A}}_i)^2 + \beta_3 (C_j - \bar{\bar{C}}_i) + \beta_4 (C_j - \bar{\bar{C}}_i)^2 + \beta_5 (F_j - \bar{\bar{F}}_i) + \beta_6 (F_j - \bar{\bar{F}}_i)^2 + \beta_7 (B_j - \bar{\bar{B}}_i) + \beta_8 (B_j - \bar{\bar{B}}_i)^2 + e_{ij}$$

where all terms are defined as they were in the model for fat trim with the following changes:

$\hat{Y}_{ij}$ = adjusted muscle,

$\bar{\bar{Y}}_i$ = mean muscle weight for the ith sex and breed group,

$(F_j - \bar{\bar{F}}_i)$ = deviation of the jth observation's total fat trim weight from the mean fat trim weight of the ith breed and sex group,

$(F_j - \bar{\bar{F}}_i)^2$ = squared deviation of the jth observation's total fat trim weight from the mean fat trim weight of the ith breed and sex group.

The results are given in Table VI.

TABLE VI

TOTAL REDUCTION SUMS OF SQUARES (TRRS) AND SQUARED MULTIPLE CORRELATION COEFFICIENTS (R^2) FOR SEVERAL MODELS TO PREDICT TOTAL CARCASS MUSCLE

Model[a]	TRSS	R^2
B, B^2, A, A^2, C, C^2, F, F^2	102,722,629	0.97
B, B^2, A, A^2, C, C^2, -, -	87,479,770	.83
B, B^2, A, A^2, -, -, F, F^2	81,118,694	.77
B, B^2, -, -, C, C^2, F, F^2	102,711,425	.97
-, -, A, A^2, C, C^2, F, F^2	102,438,053	.97
C, C^2, F, F^2	102,435,365	.97
C, C^2, -, -	81,813,651	.77
-, -, F, F^2	23,778,025	.22
C, -, F, -	102,413,741	.97
C	81,798,238	.77
F	22,108,751	.21

[a]$A = (A_j - \bar{A}_i)$ from overall model; $A^2 = (A_j - \bar{A}_i)^2$; . . . etc.

The entire model had a R^2 of 0.97. Upon deletion of variables, it was found that the equation containing carcass weight and fat accounted for a large portion of the variation ($R^2 = 0.97$). Again it was noticed that age had a small effect in these data. The simple linear model containing only carcass weight had an $R^2 = 0.77$ leaving considerable variation unaccounted for; whereas, the model using carcass weight and fat trim was the most precise.

The equation for adjusting bone was as follows:

$$\hat{Y}_{ij} = \bar{\bar{Y}}_i + \beta_1 (A_j - \bar{\bar{A}}_i) + \beta_2 (A_j - \bar{\bar{A}}_i)^2 + \beta_3 (C_j - \bar{\bar{C}}_i) + \beta_4 (C_j - \bar{\bar{C}}_i)^2 + \beta_5 (M_j - \bar{\bar{M}}_i) + \beta_6 (M_j - \bar{\bar{M}}_i)^2 + \beta_7 (F_j - \bar{\bar{F}}_i) + \beta_8 (F_j - \bar{\bar{F}}_i)^2 + e_{ij}$$

where all terms have the same definitions as in the models for fat trim and for muscle except $\hat{Y}_{ij}$ and $\bar{\bar{Y}}_i$ refer to bone rather than fat trim or muscle.

The results, when dropping variables making smallest contributions to the total reduction sums of squares, are in Table VII. From these results it was concluded that the model using carcass weight and fat trim was the most precise method for adjusting total carcass bone when using a minimum number of independent variables.

These procedures have resulted in relatively accurate methods for adjusting total carcass fat trim using carcass weight and muscle, and for adjusting total carcass muscle and bone using carcass weight and fat trim. These equations account for a large portion of the variation in carcass fat trim, muscle and bone as attested by the R^2 values of 0.96, 0.97 and 0.81, respectively. An attempt was made to predict these variables as well as percentages fat, muscle and bone, total unadjusted fat trim, muscle and bone and total carcass fat trim, muscle

TABLE VII

TOTAL REDUCTION SUMS OF SQUARES (TRSS) AND SQUARED MULTIPLE CORRELATION COEFFICIENTS (R^2) FOR SEVERAL MODELS TO PREDICT TOTAL CARCASS BONE

Model[a]	TRSS	R^2
M, M^2, A, A^2, C, C^2, F, F^2	4,098,633	0.82
M, M^2, A, A^2, C, C^2, -, -	3,953,129	.79
M, M^2, A, A^2, -, -, F, F^2	3,866,686	.78
M, M^2, -, -, C, C^2, F, F^2	4,082,693	.82
-, -, A, A^2, C, C^2, F, F^2	4,071,251	.82
C, C^2, F, F^2	4,052,395	.81
C, C^2, -, -	3,667,449	.74
C, -, F, -	4,016,683	.81
C, -, M, -	3,904,025	.78
C	3,643,947	.73
F	1,428,411	.29

[a]$A = (A_j - \bar{A}_i)$ from overall model; $A^2 = (A_j - \bar{A}_i)^2$; . . . etc.

and bone adjusted by simple linear regression for differences in carcass weight. The predictions are given in a later section.

Prediction of Variables

Most Useful Live Probes. One objective of this study was to evaluate the live animal probing technique for estimating carcass fatness. Simple correlations were used to determine which live probes of fat thickness were most highly related to carcass fat trim. Table VIII contains these correlations, for the relationship between live fat thickness measurements (unadjusted and adjusted by linear regression for live weight differences) and total carcass fat trim expressed as total weight, percentage of carcass weight, weight adjusted for carcass weight differences and weight adjusted for differences in carcass weight and total carcass muscle. Total weight of a carcass component was considered, for this is related to growth. Swiger (1962) stated that adjusting for age leaves growth rate in the carcass trait being studied. On the other hand, adjustment for differences in weight by a regression or a ratio gives a measure of composition.

None of the live probes (adjusted for live weight differences, by linear regression, or unadjusted) were significantly related to total carcass fat trim when the latter was adjusted for differences in carcass and muscle weight. The three probes, R5, R9 and R13, over the space between the 12th and 13th ribs were more highly correlated to fat expressed as total weight, percentage and weight adjusted for carcass weight differences than any of the other single live probe measurements. Combining two or three live measurements of fat thickness increased the magnitude of correlation only slightly over that

TABLE VIII

SIMPLE CORRELATION COEFFICIENTS BETWEEN LIVE FAT THICKNESS MEASUREMENTS AND CARCASS FAT TRIM

No.	Identification	Carcass Fat Trim			
				Adjusted for:	
		Weight	Percentage	Carcass Weight	Carcass Weight & Muscle
	Unadjusted[a]				
1	R5[b]	0.57**	0.55**	0.42**	0.09
2	R9[b]	.65**	.65**	.51**	.04
3	R13[b]	.58**	.62**	.52**	.18
4	T8[b]	.34*	.22	.06	-.04
5	$S_1$8[b]	.48**	.47**	.37**	.13
6	$S_1$16[b]	.42**	.41**	.33*	.10
7	$S_2$8[b]	.48**	.42**	.34*	.24
8	1 + 2 + 3 from above	.67**	.67**	.54**	.12
9	2 + 3 from above	.65**	.67**	.54**	.12
10	2 + 3 + 5 from above	.63**	.65**	.53**	.13
	Adjusted[a]				
11	R5[b]	.27	.46**	.46**	.07
12	R9[b]	.36**	.57**	.55**	.01
13	R13[b]	.35*	.55**	.55**	.16
14	T8[b]	.04	.10	.06	-.07
15	$S_1$8[b]	.25	.39**	.39**	.11
16	$S_1$16[b]	.22	.34*	.34*	.09
17	$S_2$8[b]	.24	.33*	.36**	.23
18	11 + 12 + 13 from above	.37**	.59**	.59**	.10
19	12 + 13 from above	.38**	.59**	.59**	.10
20	12 + 13 + 15 from above	.38**	.60**	.59**	.12

[a]Unadjusted or adjusted by linear regression for live weight differences.

[b]Codes defined in Materials and Methods, p. 16, 19.

*Level of significance = $P < .05$.

**Level of significance = $P < .01$.

of the single measurement having the highest correlation with carcass fat trim (see measurement numbers 8, 9, 10 and 18, 19 and 20).

No direct comparisons of the relationship of actual carcass fat and live probed fat thickness or ultrasonically measured fat thickness in beef cattle appears in the literature. Ramsey et al. (1962) reported a correlation of 0.65 between average fat thickness over the 12th rib and percentage separable fat. The live probed fat thickness measurement and percentage fat trim in this study also produced correlations near 0.65.

It appears that none of the live probes have correlations large enough to warrant their use in predictive equations for carcass fat trim adjusted for differences in carcass and muscle weight. The three probes made in the vicinity of the 12-13th rib region either singly or in combinations would have some predictive value for total fat trim unadjusted, percentage fat trim or fat trim adjusted for differences in carcass weight.

The live measurements of fat thickness were studied for their association with carcass muscle and the results are given in Table IX. None of the fat thickness measurements were very highly correlated with total unadjusted weight of muscle, or with total muscle adjusted for differences in carcass and fat weight. The live probes made over the 12-13th rib space were more highly correlated with percentage muscle and muscle adjusted for carcass weight differences than were any of the other individual probes. The unadjusted live measurements were somewhat more highly correlated with percentage muscle than were the adjusted ones; whereas, the magnitude of correlation was larger between the fat probes and carcass muscle adjusted for carcass weight when using the adjusted live probe measurements.

TABLE IX

SIMPLE CORRELATION COEFFICIENTS BETWEEN LIVE FAT THICKNESS MEASUREMENTS AND CARCASS MUSCLE

No.	Identification	Carcass Muscle			
				Adjusted for:	
		Weight	Percentage	Carcass Weight	Carcass & Fat Trim Weight
	Unadjusted[a]				
1	$R5$[b]	0.16	-.56**	-.42**	-.07
2	$R9$[b]	.13	-.64**	-.54**	-.17
3	$R13$[b]	.07	-.62**	-.50**	-.02
4	$T8$[b]	.30*	-.22	-.08	-.07
5	S_18[b]	.13	-.47**	-.35*	-.01
6	S_116[b]	.10	-.42**	-.31*	-.02
7	S_28[b]	.18	-.41**	-.27	.12
8	1 + 2 + 3 from above	.13	-.67**	-.54**	-.09
9	2 + 3 from above	.10	-.67**	-.55**	-.10
10	2 + 3 + 5 from above	.11	-.65**	-.52**	-.08
	Adjusted[a]				
11	$R5$[b]	-.22	-.48**	-.47**	-.11
12	$R9$[b]	-.24	-.58**	-.60**	-.21
13	$R13$[b]	-.22	-.56**	-.53**	-.05
14	$T8$[b]	-.03	-.12	-.09	-.10
15	S_18[b]	-.15	-.41**	-.37**	-.03
16	S_116[b]	-.13	-.36**	-.33*	-.04
17	S_28[b]	-.10	-.33*	-.29*	.11
18	11 + 12 + 13 from above	-.25	-.61**	-.60**	-.14
19	12 + 13 from above	-.24	-.60**	-.60**	-.14
20	12 + 13 + 15 from above	-.24	-.62**	-.60**	-.12

[a]Unadjusted or adjusted by linear regression for live weight differences.

[b]Codes defined in Materials and Methods, p. 16, 19.

*Level of significance = $P < .05$.

**Level of significance = $P < .01$.

On the basis of the relationships found in Tables VIII and IX, it was concluded that generally the live probe, R9, over the longissimus dorsi at the space between the 12th and 13th ribs, was the single live measurement having most predictive value for estimating carcass fat trim and/or muscle. This measurement combined with R13 yielded slightly higher correlations, so the combination of the two measurements will be considered in subsequent tables and equations for predictive purposes.

Relationship of Certain Variables to Carcass Fat Trim. Table X contains simple correlation coefficients between several live and carcass measurements thought to have an association with total carcass fat trim. One method commonly employed for estimating condition or fatness of livestock is subjective evaluation. The results of this inquiry suggest that the live measurements of fatness by use of the probing needle are more highly associated with carcass fat trim than are the subjective scores used by graders A, B or C. The graders' scores were not as highly correlated with fat trim in this study as they were with carcass cutability according to Gregory et al. (1962). The cattle in this study were less variable in fatness (Table III) which may have caused lower relationships than found by Gregory.

The live probed fat measurement, R9 + R13, was slightly more highly correlated to percentage carcass fat trim ($r = 0.67$) than were the carcass fat thickness measurements ($r = 0.64$). The same trend existed when the live and carcass fat thicknesses were related to fat trim adjusted for differences in carcass weight ($r = 0.59$ and 0.50, respectively). It may be concluded that the probing technique will yield as much information concerning carcass fat trim in the live

TABLE X

SIMPLE CORRELATION COEFFICIENTS BETWEEN CERTAIN LIVE AND CARCASS MEASUREMENTS AND CARCASS FAT TRIM

Measurement	Carcass Fat Trim			
			Adjusted for:	
	Weight	Percentage	Carcass Weight	Carcass & Muscle Weight
Live				
R9 unadjusted	0.65**	0.65**	0.51**	0.04
R9 adjusted for live wt.	.36**	.57**	.55**	.01
R9 + R13 unadjusted	.65**	.67**	.54**	.12
R9 + R13 adjusted for live wt.	.38**	.59**	.59**	.10
Condition - grader A	.62**	.44**	.27	.15
grader B	.45**	.29*	.11	.09
grader C	.50**	.29*	.12	.21
Muscling - grader A	.46**	.25	.15	.42**
grader B	.37**	.18	.07	.23
Live weight	.79**	.32*	.01	.07
Weight per day of age	.63**	.23	-.00	.07
Carcass				
Average fat thickness	.66**	.64**	.51**	.18
Single fat thickness	.67**	.64**	.50**	.16
Estimated kidney fat (%)	.51**	.50**	.41**	.27
Specific gravity	-.64**	-.77**	-.70**	-.32*
Longissimus dorsi area	.06	-.36**	-.53**	-.02
Hot carcass weight	.81**	.35*	.02	.05
Marbling	.31*	.41**	.37**	.27
Conformation	.21	.19	.15	.19
Final grade	.48**	.57**	.55**	.38**
Trimmed round - weight	.62**	.10	-.20	-.06
Trimmed round - percentage of carcass	-.52**	-.62**	-.50**	-.24
Carcass cutability - MA[a]	-.70**	-.79**	-.69**	-.21
MS[b]	-.75**	-.80**	-.69**	-.21
BB[c]	-.65**	-.72**	-.58**	-.26

[a]Murphey *et al.* (1960) equation using average fat thickness.
[b]Murphey *et al.* (1960) equation using single fat thickness.
[c]Brungardt and Bray (1963) cutability equation.
*Level of significance = $P < .05$.
**Level of significance = $P < .01$.

animal as would be obtained from the 12th rib carcass fat thickness measurement after slaughter. This is of value to the cattle breeder for he could speed progress by at least one generation for this particular trait. This same trend was noticed in swine by Hazel and Kline (1952, 1959) and Bowman (1962) who reported that live measurements were more highly related to actual carcass yields than were the carcass fat thickness measurements.

On the basis of relationships presented in Table X and the practicality of the measurement, certain variables were combined for predictive purposes. The squared multiple correlation coefficients were used to evaluate the combination. The set of equations for the variables considered most useful were solved, so that prediction equations could be presented. The combinations of variables examined relative to total weight of fat trim are given in Table XI.

The results in Table XI indicate that a higher relationship exists between the set of variables comprised of carcass measurements than the set coming from live measurements. The addition of grader A's condition score and weight per day of age to set number one increased the correlation coefficient only slightly. Substitution of the live fat thickness measurement in place of the carcass measurement did not improve the correlation as shown by the R^2 values given for sets numbered two and three, respectively.

The combinations of variables considered for predicting percentage carcass fat trim are given in Table XII. These results suggest that considerable accuracy would be sacrificed when using only the live measurements presented as combination number one. The proportionate increase in R^2 attributable to grader A and weight per day

TABLE XI

SQUARED MULTIPLE CORRELATION COEFFICIENTS (R^2) BETWEEN CERTAIN SETS OF VARIABLES AND TOTAL WEIGHT OF CARCASS FAT TRIM

Set No.	Variable Added	Contribution to R^2	R^2
1 - Live measurements	Live weight	0.619	0.619
	Fat thickness - live R9-U[a]	.131	.750
	Condition - grader A	.012	.762
	Weight/day of age	.002	.764
2 - Carcass measurements	Hot carcass weight	0.663	0.663
	Fat thickness - single	.105	.767
	Estimated kidney fat	.054	.821
	Longissimus dorsi area	.035	.856
3 - Live and carcass	Hot carcass weight	0.663	0.663
	Fat thickness - live R9-U[a]	.105	.768
	Estimated kidney fat	.045	.813
	Longissimus dorsi area	.034	.846

[a]U = unadjusted for differences in live weight.

TABLE XII

SQUARED MULTIPLE CORRELATION COEFFICIENTS (R^2) BETWEEN CERTAIN SETS OF VARIABLES AND PERCENTAGE FAT TRIM

Set No.	Variable Added	Contribution to R^2	R^2
1 - Live measurements	Live weight	0.103	0.103
	Fat thickness - live R9-U[a]	.328	.431
	Condition - grader A	.035	.466
	Weight/day of age	.018	.484
2 - Carcass measurements	Hot carcass weight	0.122	0.122
	Fat thickness - single	.284	.406
	Estimated kidney fat	.140	.547
	Longissimus dorsi area	.100	.646
3 - Live and carcass	Hot carcass weight	0.122	0.122
	Fat thickness - live R9 + R13-U[a]	.333	.455
	Estimated kidney fat	.119	.573
	Longissimus dorsi area	.081	.654

[a]U = unadjusted for differences in live weight.

of age after live weight and R9 probe is small and perhaps of questionable value.

The relationships of live and carcass weight to percentage fat trim should have theoretically been zero, if the ratio was useful in adjusting for differences in weight. The fact that live and carcass weights had R^2 values of 0.10 and 0.12, respectively, indicates that the ratio did not remove all of the variation attributable to weight differences. Previously cited works by Swiger (1962), Dinkel et al. (1965) and Esplin et al. (1964) suggested one should expect this to occur.

A combination of carcass measurements used in the equations given by Murphey et al. (1960) yielded an R^2 of 0.65. This value differs little from 0.64 which was obtained by squaring the simple correlation coefficient between carcass cutability, MS, and percentage carcass fat in Table X. This suggests that the weights attached to these variables by Murphey and co-workers serve to represent the carcasses in this study nearly as well as would an equation developed from these data.

Variables listed as combination three in Table XII suggest that the live probed fat measurement, R9 + R13, is of somewhat more value for predicting percentage fat trim than is the single carcass fat thickness measurement. The proportionate reduction in sums of squares after carcass weight is 0.05 units larger. Observation of the proportionate increase in value for estimated kidney fat and *longissimus dorsi* area indicates that the live probed fat measurement accounts for some of the variation in these two variables unaccounted for by the single carcass fat thickness measurement. This is perhaps the cause of a decrease by 0.02 units each in reduction sums of squares for estimated kidney fat and longissimus dorsi area.

The prediction of percentage fat trim ($\hat{Y}_{ij}$) may be made from the following two equations:

Live measurements--set number one, Table XII.

$$\hat{Y}_{ij} = \bar{Y}_i + 0.0090\ (L_j - \bar{L}_i) + 6.6399\ (R_j - \bar{R}_i) + 0.7113\ (C_j - \bar{C}_i) - 8.2488\ (W_j - \bar{W}_i)$$

where:

$\bar{Y}_i$ = mean percentage fat trim for the ith breed and sex group,

$(L_j - \bar{L}_i)$ = deviation of the jth observation's live weight (kilograms) from the mean weight of the ith group,

$(R_j - \bar{R}_i)$ = as above for fat thickness - live R9 (cm.),

$(C_j - \bar{C}_i)$ = as above for condition score - grader A and

$(W_j - \bar{W}_i)$ = as above for weight per day of age (kilograms).

Carcass measurements--set number two, Table XII.

$$\hat{Y}_{ij} = \bar{Y}_i + 0.0293\ (W_j - \bar{W}_i) + 4.1650\ (F_j - \bar{F}_i) + 2.2076\ (K_j - \bar{K}_i) - 0.1888\ (R_j - \bar{R}_i)$$

where:

$\bar{Y}_i$ = mean percentage fat for the ith breed and sex group,

$(W_j - \bar{W}_i)$ = deviation of the jth observation's hot carcass weight (kilograms) from the mean weight of the ith group,

$(F_j - \bar{F}_i)$ = as above for single carcass fat thickness (cm.),

$(K_j - \bar{K}_i)$ = as above for estimated kidney fat (percentage) and

$(R_j - \bar{R}_i)$ = as above for area of longissimus dorsi (sq. cm.).

Two sets of variables were used in an attempt to predict fat trim adjusted for differences in carcass weight and appear in Table XIII. Again the live fat measurement compares favorably with the carcass fat thickness measurement.

The prediction of fat trim adjusted by linear regression for differences in carcass weight ($\hat{Y}_{ij}$) may be made from the following two equations:

Live measurements--set number one, Table XIII.

$$\hat{Y}_{ij} = \bar{\bar{Y}}_i + 8.8462\ (R_j - \bar{\bar{R}}_i) + 0.5588\ (C_j - \bar{\bar{C}}_i) + 1.2873\ (M_j - \bar{\bar{M}}_i)$$

where:

$\bar{\bar{Y}}_i$ = mean weight of fat trim for the ith breed and sex group,

$(R_j - \bar{\bar{R}}_i)$ = deviation of the jth observation's fat thickness (live R9 + R13, cm., adjusted by linear regression for differences in live weight) from the mean fat thickness of the ith group,

$(C_j - \bar{\bar{C}}_i)$ = as above for condition score--grader A and

$(M_j - \bar{\bar{M}}_i)$ = as above for muscling score--grader A.

Carcass Measurements--set number two, Table XIII.

$$\hat{Y}_{ij} = \bar{\bar{Y}}_i + 9.5639\ (F_j - \bar{\bar{F}}_i) + 5.6031\ (K_j - \bar{\bar{K}}_i) - 0.5541\ (R_j - \bar{\bar{R}}_i)$$

where:

$\bar{\bar{Y}}_i$ = mean weight of fat trim for the ith breed and sex group,

$(F_j - \bar{\bar{F}}_i)$ = deviation of the jth observation's single carcass fat thickness (cm.) from the mean fat thickness of the ith group,

TABLE XIII

SQUARED MULTIPLE CORRELATION COEFFICIENTS (R^2) BETWEEN CERTAIN SETS OF VARIABLES AND FAT TRIM ADJUSTED FOR CARCASS WEIGHT

Set No.	Variable Added	Contribution to R^2	R^2
1 - Live measurements	Fat thickness - live R9 + R13-A[a]	0.333	0.333
	Condition - grader A	.024	.357
	Muscling - grader A	.016	.373
2 - Carcass measurements	Fat thickness - single	0.249	0.249
	Estimated kidney fat	.097	.346
	Longissimus dorsi area	.224	.569
3 - Live and carcass	Fat thickness - live R9 + R13-A[a]	0.343	0.343
	Estimated kidney fat	.115	.458
	Longissimus dorsi area	.115	.573

[a]A = adjusted by linear regression for live weight differences.

$(K_j - \bar{K}_i)$ = as above for estimated kidney fat (percentage) and

$(R_j - \bar{R}_i)$ = as above for area of longissimus dorsi (sq. cm.).

Relationship of Certain Variables to Carcass Muscle. The relationships of several variables to carcass muscle are given in Table XIV. The live fat thickness measurements are more highly correlated to percentage muscle or muscle adjusted for differences in carcass weight than any of the other single measurements considered. The two cutability equations (Murphey *et al.*, 1960), each of which considers four factors, are more highly correlated to carcass muscle expressed as a percentage or adjusted for carcass weight than ony of the other variables considered. The correlation of 0.76 and 0.79 between predicted cutability and percentage yield of muscle are very similar to the one given by Palmer *et al.* (1961). Palmer found a correlation of 0.76 between cooler estimated cutability and actual yield of boneless retail cuts.

The correlation of 0.88 between hot carcass weight and total carcass muscle is substantiated by Fitzhugh *et al.* (1965) who found that carcass weight alone accounted for more variation in steak and roast meat than any combination of other variables. This relationship is to be expected since carcass weight was quite variable. Fitzhugh reported a standard deviation of 31 kilograms for this trait; whereas, the standard deviation was 27 kilograms in these data for carcass weight.

Very low correlations were found between most of the variables and carcass muscle after adjusting for differences in fat and carcass weight. Even though the equation which adjusted carcass muscle for these two variables had a multiple correlation coefficient of 0.97,

TABLE XIV

SIMPLE CORRELATION COEFFICIENTS BETWEEN CERTAIN LIVE AND CARCASS MEASUREMENTS AND CARCASS MUSCLE

Measurement	Carcass Muscle Weight	Carcass Muscle Percentage	Adjusted for: Carcass Weight	Adjusted for: Carcass & Fat Trim Weight
Live				
R9 unadjusted	0.13	-.64**	-.54**	-.17
R9 adjusted for live wt.	-.24	-.58**	-.60**	-.21
R9 + R13 unadjusted	.10	-.67**	-.55**	-.10
R9 + R13 adjusted for live wt.	-.24	-.60**	-.60**	-.13
Conformation - grader A	.41**	-.10	.01	-.03
grader B	.60**	-.09	.14	.18
grader C	.53**	-.07	.13	.11
Muscling - grader A	.41**	-.19	.01	.40**
grader B	.38**	-.12	.02	.23
Live weight	.86**	-.28*	.02	.07
Weight per day of age	.70**	-.21	.03	.07
Carcass				
Average fat thickness	.17	-.58**	-.48**	-.02
Single fat thickness	.19	-.60**	-.48**	-.03
Estimated kidney fat (%)	.15	-.46**	-.33*	.12
Specific gravity	.05	.70**	.63**	-.06
Carcass conformation	.09	-.11	-.08	.15
Longissimus dorsi area	.68**	.42**	.57**	.20
Trimmed round - weight	.90**	-.07	.19	.01
Trimmed round - percentage of carcass	-.04	.55**	.44**	-.06
Hot carcass weight	.88**	-.30*	-.00	.05
Carcass cutability - MA[a]	-.02	.76**	.66**	.06
MS[b]	-.06	.79**	.67**	.06
BB[c]	-.09	.65**	.53**	-.04

[a]Murphey *et al.* (1960) equation using average fat thickness.
[b]Murphey *et al.* (1960) equation using single fat thickness.
[c]Brungardt and Bray (1963) cutability equation.
*Level of significance = P <.05.
**Level of significance = P <.01.

it is apparently of little value for two reasons. The first is that muscle can only be adjusted for differences in fat trim when the latter is measured, and usually when fat trim is measured, total muscle is also measured. The second reason is that, even if the equation is highly accurate, it is of little practical value if it cannot be predicted short of a complete cutting operation.

Multiple correlation coefficients were calculated between total muscle weight and certain combinations of variables from Table XIV. The results appear in Table XV. The last three variables included in set number one in Table XV added little to the mutliple correlation coefficient after live weight had made its contribution. When live weight is known, the addition of weight per day of age and the conformation and muscling scores from grader B is of little value. The combination of live weight and the R9 fat probe would have more value for predicting total carcass muscle than would the entire group of variables called set number one.

Considerably more accuracy can be obtained when the carcass measurements included in set number three are used for predicting total carcass muscle. The use of the live probed fat measurement did not add to the precision of estimating carcass muscle as compared to using the single carcass fat thickness measurement at the 12th rib.

The variables grouped together for predicting percentage carcass muscle are given in Table XVI. Set number two is comprised of the same variables used in the currently popular equation for predicting carcass cutability by Murphey et al. (1960). The R^2 of 0.63 is very similar to the r^2 of 0.62 from Table XIV which suggests that the Murphey et al. (1960) equation is of nearly equal predictive value to one

TABLE XV

SQUARED MULTIPLE CORRELATION COEFFICIENTS (R^2) BETWEEN CERTAIN SETS OF VARIABLES AND TOTAL WEIGHT OF CARCASS MUSCLE

Set No.	Variable Added	Contribution to R^2	R^2
1 - Live measurements	Live weight	0.745	0.745
	Weight/day of age	.002	.746
	Conformation - grader B	.006	.753
	Muscling - grader B	.003	.755
2 - Live measurements	Live weight	0.745	0.745
	Fat thickness - live R9-A[a]	.058	.803
3 - Carcass measurements	Hot carcass weight	0.772	0.772
	Longissimus dorsi area	.093	.866
	Fat thickness - single	.015	.881
	Estimated kidney fat	.016	.897
4 - Live and carcass	Hot carcass weight	0.772	0.772
	Longissimus dorsi area	.093	.866
	Fat thickness - live R9-A[a]	.024	.890
	Estimated kidney fat	.002	.892

[a]A = adjusted by linear regression for live weight differences.

TABLE XVI

SQUARED MULTIPLE CORRELATION COEFFICIENTS (R^2) BETWEEN CERTAIN SETS OF VARIABLES AND PERCENTAGE CARCASS MUSCLE

Set No.	Variable Added	Contribution to R^2	R^2
1 - Live measurements	Live weight	0.081	0.081
	Fat thickness - live R9-U[a]	.333	.413
	Weight/day of age	.015	.428
	Muscling - grader A	.015	.443
2 - Carcass measurements	Hot carcass weight	0.090	0.090
	Fat thickness - single	.268	.358
	Estimated kidney fat	.129	.487
	Longissimus dorsi area	.143	.630
3 - Live and carcass	Hot carcass weight	0.090	0.090
	Fat thickness - live R9 + R13-U[a]	.353	.443
	Estimated kidney fat	.107	.550
	Longissimus dorsi area	.107	.657

[a]U = unadjusted for differences in live weight.

which could be developed from these data for predicting percentage carcass muscle.

The R^2 of 0.66 for set number three suggests that the live probed fat thickness measurements, R9 + R13, unadjusted for live weight are of slightly more value for predicting percentage muscle than is the single carcass fat thickness measurement.

The prediction of percentage carcass muscle ($\hat{Y}_{ij}$) may be made by the following two equations:

Live measurements--set number one, Table XVI.

$$\hat{Y}_{ij} = \bar{Y}_i - 0.0062\ (L_j - \bar{L}_i) - 6.4422\ (R_j - \bar{R}_i) + 6.0943\ (W_j - \bar{W}_i) - 0.4126\ (M_j - \bar{M}_i)$$

where:

$\bar{Y}_i$ = mean percentage muscle for the ith breed and sex group,

$(L_j - \bar{L}_i)$ = deviation of the jth observation's live weight (kilograms) from the mean weight of the ith group,

$(R_j - \bar{R}_i)$ = as above for fat thickness - live R9 (cm.),

$(W_j - \bar{W}_i)$ = as above for weight per day of age (kilograms) and

$(M_j - \bar{M}_i)$ = as above for muscling score - grader A.

Carcass measurements--set number two, Table XVI.

$$\hat{Y}_{ij} = \bar{Y}_i - 0.0283\ (W_j - \bar{W}_i) - 3.1251\ (F_j - \bar{F}_i) - 1.7939\ (K_j - \bar{K}_i) + 0.1987\ (R_j - \bar{R}_i)$$

where:

$\bar{Y}_i$ = mean percentage muscle for the ith breed and sex group,

$(W_j - \bar{W}_i)$ = deviation of the jth observation's hot carcass weight (kilograms) from the mean weight of the ith group,

$(F_j - \bar{F}_i)$ = as above for single carcass fat thickness (cm.),

$(K_j - \bar{K}_i)$ = as above for estimated kidney fat (percentage) and

$(R_j - \bar{R}_i)$ = as above for longissimus dorsi area (sq. cm.).

Hot carcass weight was excluded from the last two sets of variables in Table XVI to predict total carcass muscle adjusted for carcass weight in Table XVII. Multiple correlations of 0.55 and 0.56 were obtained from the equations which contained carcass and live fat thickness measurements, respectively, in addition to estimated kidney fat and longissimus dorsi area.

The prediction of muscle adjusted for differences in carcass weight $(\hat{Y}_{ij})$ may be made by the following two equations:

Live measurements--set number one, Table XVII.

$$\hat{Y}_{ij} = \bar{Y}_i - 7.0992\,(R_j - \bar{R}_i) - 1.1835\,(C_j - \bar{C}_i) + 1.1563\,(G_j - \bar{G}_i)$$

where:

$\bar{Y}_i$ = mean weight of muscle for the ith breed and sex group,

$(R_j - \bar{R}_i)$ = deviation of the jth observation's fat thickness (live R9 + R13, cm., adjusted by linear regression for differences in live weight) from the mean fat thickness of the ith group,

$(C_j - \bar{C}_i)$ = as above for condition score - grader A and

$(G_j - \bar{G}_i)$ = as above for conformation score - grader B.

TABLE XVII

SQUARED MULTIPLE CORRELATION COEFFICIENTS (R^2) BETWEEN CERTAIN SETS OF VARIABLES AND TOTAL CARCASS MUSCLE ADJUSTED FOR CARCASS WEIGHT

Set No.	Variable Added	Contribution to R^2	R^2
1 - Live measurements	Fat thickness - live R9 + R13-A[a]	0.357	0.357
	Condition - grader A	.013	.370
	Conformation - grader B	.014	.384
2 - Carcass measurements	Fat thickness - single	0.226	0.226
	Estimated kidney fat	.058	.284
	Longissimus dorsi area	.263	.547
3 - Live and carcass	Fat thickness - live R9 + R13-A[a]	0.357	0.357
	Estimated kidney fat	.070	.426
	Longissimus dorsi area	.137	.564

[a] A = adjusted by linear regression for live weight differences.

Carcass measurements--set number two, Table XVII.

$$\hat{Y}_{ij} = \bar{Y}_i - 7.8874\,(F_j - \bar{F}_i) - 3.8680\,(K_j - \bar{K}_i) + 0.5179\,(R_j - \bar{R}_i)$$

where:

$\bar{Y}_i$ = mean weight of muscle for the ith breed and sex group,

$(F_j - \bar{F}_i)$ = deviation of the jth observation's single carcass fat thickness (cm.) from the mean fat thickness of the ith group,

$(K_j - \bar{K}_i)$ = as above for estimated kidney fat (percentage) and

$(R_j - \bar{R}_i)$ = as above for *longissimus dorsi* area (sq. cm.).

Relationship of Certain Variables to Carcass Bone. Several correlations between carcass bone and other variables are given in Table XVIII. The variables most highly correlated to bone are those which measured carcass size, and the larger carcasses yielded more bone.

Somewhat surprising are the relationships between carcass measured fat thickness and percentage bone. Apparently, increased carcass fatness is associated with a lowered percentage of bone. This does not necessarily mean that less bone exsits in those carcasses having a higher percentage of fat trim, but rather this relationship is encountered because of the spurious correlation imposed by virtue of the ratios involved.

Apparently the measurements included in Table XVIII are not very highly correlated with carcass bone adjusted for carcass weight differences, or adjusted for carcass and fat weight differences. The positive association between percentage round and weight of bone adjusted for carcass weight differences may lead to the conclusion that

TABLE XVIII

SIMPLE CORRELATION COEFFICIENTS BETWEEN CERTAIN LIVE AND CARCASS MEASUREMENTS AND CARCASS BONE

Measurement	Carcass Bone			
			Adjusted for:	
	Weight	Percentage	Carcass Weight	Carcass & Fat Trim Weight
Live				
R9 unadjusted	.24	-.41**	-.26	-.01
R9 adjusted for live wt.	-.12	-.30*	-.32*	-.03
Conformation - grader A	.43**	-.09	.08	.08
grader B	.62**	-.11	.20	.18
grader C	.46**	-.23	.01	-.05
Muscling - grader A	.31*	-.39**	-.15	-.08
grader B	.28*	-.33*	-.14	-.12
Live weight	.87**	-.33*	.07	.09
Age	.32*	-.23	-.09	-.10
Weight per day of age	.74**	-.21	.15	.17
Carcass				
Average fat thickness	0.13	-.62**	-.49**	-.26
Single fat thickness	.23	-.51**	-.35*	-.10
Estimated kidney fat (%)	.17	-.41**	-.25	-.04
Specific gravity	.10	.73**	.66**	.33**
Longissimus dorsi area	.47**	-.05	.14	-.17
Trimmed round - weight	.90**	-.15	.23	.15
Trimmed round - percentage of carcass	.04	.62**	.54**	.33**
Hot carcass weight	.85**	-.40**	-.00	.01
Carcass cutability - MA[a]	-.11	.54**	.41**	.05
MS[b]	-.20	.50**	.33*	-.04
BB[c]	-.04	.69**	.57**	.31*

[a]Murphey *et al.* (1960) equation using average fat thickness.
[b]Murphey *et al.* (1960) equation using single fat thickness.
[c]Brungardt and Bray (1963) cutability equation.
*Level of significance = $P < .05$.
**Level of significance = $P < .01$.

more bone is associated with the carcasses having a larger portion of their weight in the round wholesale cut.

Three groups of variables were combined and multiple correlation coefficients were computed between them and total weight of carcass bone. The findings are submitted in Table XIX. From this table it appears that the combination of weight of the trimmed round and a single carcass fat thickness measurement are rather highly associated with total carcass bone. In fact, these two variables are more highly correlated with total carcass bone than are the combinations of four variables given in set numbers one and three.

The relationships of certain measurements to percentage bone and bone adjusted for differences in carcass weight are presented in Tables XX and XXI. More precision is obtained when using carcass measurements in both cases. The live measurements used to predict bone adjusted for carcass weight netted a very low R^2.

The prediction of percentage carcass bone ($\hat{Y}_{ij}$) may be made by the following two equations:

Live measurements--set number one, minus conformation and age, Table XX.

$$\hat{Y}_{ij} = \bar{Y}_i - 0.8887\ (F_j - \bar{F}_i) - 0.2558\ (M_j - \bar{M}_i)$$

where:

$\bar{Y}_i$ = mean percentage bone for the ith breed and sex group,

$(F_j - \bar{F}_i)$ = deviation of the jth observation's fat thickness (live R9, cm.) from the mean fat thickness of the ith group and

$(M_j - \bar{M}_i)$ = as above for muscling score - grader A.

TABLE XIX

SQUARED MULTIPLE CORRELATION COEFFICIENTS (R^2) BETWEEN CERTAIN SETS OF VARIABLES AND TOTAL WEIGHT OF CARCASS BONE

Set No.	Variable Added	Contribution to R^2	R^2
1 - Live measurements	Live weight	0.756	0.756
	Fat thickness - live R9-U[a]	.015	.770
	Weight/day of age	.017	.787
	Conformation - grader B	.006	.793
2 - Carcass measurements	Trimmed round weight	0.814	0.814
	Fat thickness - single	.009	.823
	Longissimus dorsi area	.002	.825
	Estimated kidney fat	.003	.828
3 - Live and carcass	Hot carcass weight	0.730	0.730
	Fat thickness - single	.042	.772
	Estimated kidney fat	.016	.788
	Conformation - grader B	.007	.795

[a]U = unadjusted for differences in live weight.

TABLE XX

SQUARED MULTIPLE CORRELATION COEFFICIENTS (R^2) BETWEEN CERTAIN SETS OF VARIABLES AND PERCENTAGE CARCASS BONE

Set No.	Variable Added	Contribution to R^2	R^2
1 - Live measurements	Fat thickness - live R9-U[a]	0.171	0.171
	Muscling - grader A	.127	.298
	Conformation - grader C	.004	.302
	Age	.010	.312
2 - Carcass measurements	Hot carcass weight	0.161	0.161
	Fat thickness - single	.131	.292
	Estimated kidney fat	.072	.364
	Longissimus dorsi area	.006	.370

[a]U = unadjusted for differences in live weight.

TABLE XXI

SQUARED MULTIPLE CORRELATION COEFFICIENTS (R^2) BETWEEN CERTAIN SETS OF VARIABLES AND BONE ADJUSTED FOR CARCASS WEIGHT

Set No.	Variable Added	Contribution to R^2	R^2
1 - Live measurements	Fat thickness - live R9-A[a]	0.100	0.100
	Conformation - grader B	.021	.121
	Weight/day of age	.018	.139
2 - Carcass measurements	Fat thickness - single	0.119	0.119
	Estimated kidney fat	.033	.152
	Longissimus dorsi area	.009	.161

[a]A = adjusted by linear regression for live weight differences.

Carcass measurements--set number two, Table XX.

$$\hat{Y}_{ij} = \bar{Y}_i - 0.0050\ (W_j - \bar{W}_i) - 0.8130\ (F_j - \bar{F}_i) - 0.3758\ (K_j - \bar{K}_i) - 0.0099\ (R_j - \bar{R}_i)$$

where:

$\bar{Y}_i$ = mean percentage bone for the ith breed and sex group,

$(W_j - \bar{W}_i)$ = deviation of the jth observation's hot carcass weight (kilograms) from the mean hot carcass weight of the ith group,

$(F_j - \bar{F}_i)$ = as above for single carcass fat thickness (cm.),

$(K_j - \bar{K}_i)$ = as above for estimated kidney fat (percentage) and

$(R_j - \bar{R}_i)$ = as above for longissimus dorsi area (sq. cm.).

The prediction of bone adjusted for differences in carcass weight $(\hat{Y}_{ij})$ may be made by the following two equations:

Live measurements--set number one, Table XXI.

$$\hat{Y}_{ij} = \bar{Y}_i - 1.9678\ (R_j - \bar{R}_i) + 0.1587\ (C_j - \bar{C}_i) + 2.9834\ (W_j - \bar{W}_i)$$

where:

$\bar{Y}_i$ = mean weight of bone for the ith breed and sex group,

$(R_j - \bar{R}_i)$ = deviation of the jth observation's fat thickness (live R9, cm., adjusted by linear regression for differences in live weight) from the mean fat thickness of the ith group,

$(C_j - \bar{C}_i)$ = as above for conformation score - grader B and

$(W_j - \bar{W}_i)$ = as above for weight per day of age.

Carcass measurements--set number two, Table XXI.

$$\hat{Y}_{ij} = \bar{Y}_i - 1.6914\ (F_j - \bar{F}_i) - 0.6335\ (K_j - \bar{K}_i) + 0.0225\ (R_j - \bar{R}_i)$$

where:

$\bar{Y}_i$ = mean weight of bone for the ith breed and sex group,

$(F_j - \bar{F}_i)$ = deviation of the jth observation's single carcass fat thickness (cm.) from the mean fat thickness of the ith group,

$(K_j - \bar{K}_i)$ = as above for estimated kidney fat (percentage) and

$(R_j - \bar{R}_i)$ = as above for longissimus dorsi area (sq cm.).

SUMMARY

Fat thickness was measured alive and in the carcass on 380 bulls, steers and heifers. Simple correlation coefficients between the live and carcass measurements over the <u>longissimus</u> <u>dorsi</u> at the 12-13th rib ranged in magnitude from 0.21 to 0.90 with a major portion of the estimates occurring between 0.50 and 0.80. All analyses were computed within breed and sex group.

The second phase of the study was comprised of 13, 10 and 8 Angus bulls, steers and heifers, respectively, and 20 Hereford steers. Live probes of fat thickness were taken at seven locations on the animal in addition to other conventional live animal measurements. The accuracy of certain combinations of live measurements were compared with carcass measurements for predicting carcass composition. The results are summarized in Table XXII. They indicate that some precision is sacrificed when measurements are made in the live animal. This sacrifice in precision is perhaps not large enough to warrant a progeny test for selection if the heritability of the trait is high.

The use of regressions and ratios was examined for adjusting data from carcasses differing in weight. Simple correlations between percentages fat, muscle and bone and fat, muscle and bone adjusted by simple linear regression were 0.92, 0.92 and 0.89, respectively. It was concluded that the two methods of adjustment were providing similar answers.

TABLE XXII

MULTIPLE CORRELATION COEFFICIENTS BETWEEN LIVE AND CARCASS MEASUREMENTS AND CARCASS COMPOSITION

Carcass Components Expressed As:	Component					
	Fat Trim		Muscle		Bone	
	Estimated From Measurements Taken:					
	Live	Carcass	Live	Carcass	Live	Carcass
Total weight	0.87**	0.93**	0.90**	0.95**	0.89**	0.91**
Percentage	.69**	.80**	.66**	.79**	.56**	.61**
Adjusted by regression	.61**	.75**	.62**	.74**	.37	.40*

*Level of significance = $P < .05$.
**Level of significance = $P < .01$.

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APPENDIX

DESCRIPTION OF MUSCLING SCORE

Using a scoring system of all integers from 1 to 15, indicate the animal possessing ideal muscling with a score of 15. The extremely angular type, which is extremely deficient in muscling should receive a score of 1. All others should be scored according to their individual merit between 1 and 15.

When observing an animal, to access muscling, primary emphasis should be placed on the muscling indicators of the hind-quarter of the animal. Thickly muscled quarters which have the greatest dimensions relative to the entire animal are most desirable. Muscles which define themselves as the animal moves are less likely to be covered by fat, and therefore should be considered valuable indicators of muscling. Secondary emphasis may be placed on the muscling evident in the forearm and shoulder region. (Extremely desirable muscling in the quarters will normally be accompanied with heavy muscling throughout the animal.)

Minor consideration will be given to the muscling of the crops, back and loin for these regions are readily covered by fat and therefore are difficult to appraise accurately.

VITA

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